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Predicted climate change effects on European perch (*Perca fluviatilis* L.) - A case study from the Curonian Lagoon, south-eastern Baltic

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ABSTRACT

Climate change is likely to increasingly impact estuarine fish populations. Changes in water temperature or salinity can have deleterious effects on fish growth and behaviour. A decrease in the abundance of freshwater fish in the northern areas of the Curonian Lagoon has been attributed to increased salinity of inflowing water from the Baltic Sea. Thus, this study investigated the effects of possible changes in environmental salinity and temperature on the growth and behaviour of perch (*Perca fluviatilis* L.). Laboratory experiments revealed that brackish water (salinity 3 and 6) has neither a negative nor a positive effect on growth rates among perch young-of-the-year, when compared to freshwater (salinity 0). In contrast, results from behavioural experiments demonstrated that perch prefer to remain in brackish water (salinity 6) when given a choice between brackish and freshwater, and in warm water (18 °C) when given a choice between warm and cold water (12 °C). For this reason, the temperature rather than the salinity of inflowing colder brackish water from the Baltic Sea will be the most likely driver of short-term changes in fish distribution in the Curonian Lagoon.

1. Introduction

Global climate change is one of the major threats to marine and estuarine fish and fisheries (Roessig et al., 2004). Water salinity and temperature are greatly affected by climate (Roessig et al., 2004), as well as sea level which has risen 0.19 m over the past century (Pachauri et al., 2014). Water salinity, temperature and sea level rise are interconnected. Rising sea levels result in a landward shift of the estuarine salinity levels (Etemad-Shahidi et al., 2015). Increased sea level and concomitant changes in water temperature and salinity have tremendous implications for coastal environments, including both direct and indirect effects on fish, their populations, and those communities which rely on fishing as a source of income or recreation (Roessig et al., 2004; Fujii, 2012; Etemad-Shahidi et al., 2015). Increasing influxes of seawater driving ever further into the estuaries can alter the upstream conditions to which freshwater fish are adapted with adverse trophic, physiological, reproductive and behavioural consequences impacting their survival.

In estuaries, salinity can be a primary factor determining fish distribution patterns (Ley et al., 1999; Jung and Houde, 2003), feeding and growth (Lankford and Targett, 1994; Boeuf and Payan, 2001) and community structure (Edeline et al., 2005). It has been speculated that increasing inflow of brackish water into the Curonian Lagoon may significantly alter the ecosystem and reduce fisheries productivity in the northern part of the Lagoon (Bukantis et al., 2008), although this interpretation has not been supported by any direct evidence. Estuarine species typically have to cope with large salinity fluctuations. Levels of stress vary with the osmoregulatory capacity and behavioural response of each species (Serafy et al., 1997). However, it is generally accepted that salinities close to the osmolality of the blood (isosmotic) minimize the physiological costs of osmoregulation, saving more energy for other processes, such as growth and reproduction (Lankford and Targett, 1994; Cardona, 2000; Boeuf and Payan, 2001; Imsland et al., 2001; Hurst and Conover, 2002). Therefore, the negative effects of low salinity (up to 7) on freshwater fish species are questionable (Christensen et al., 2016a,b). Other environmental factors such as water temperature

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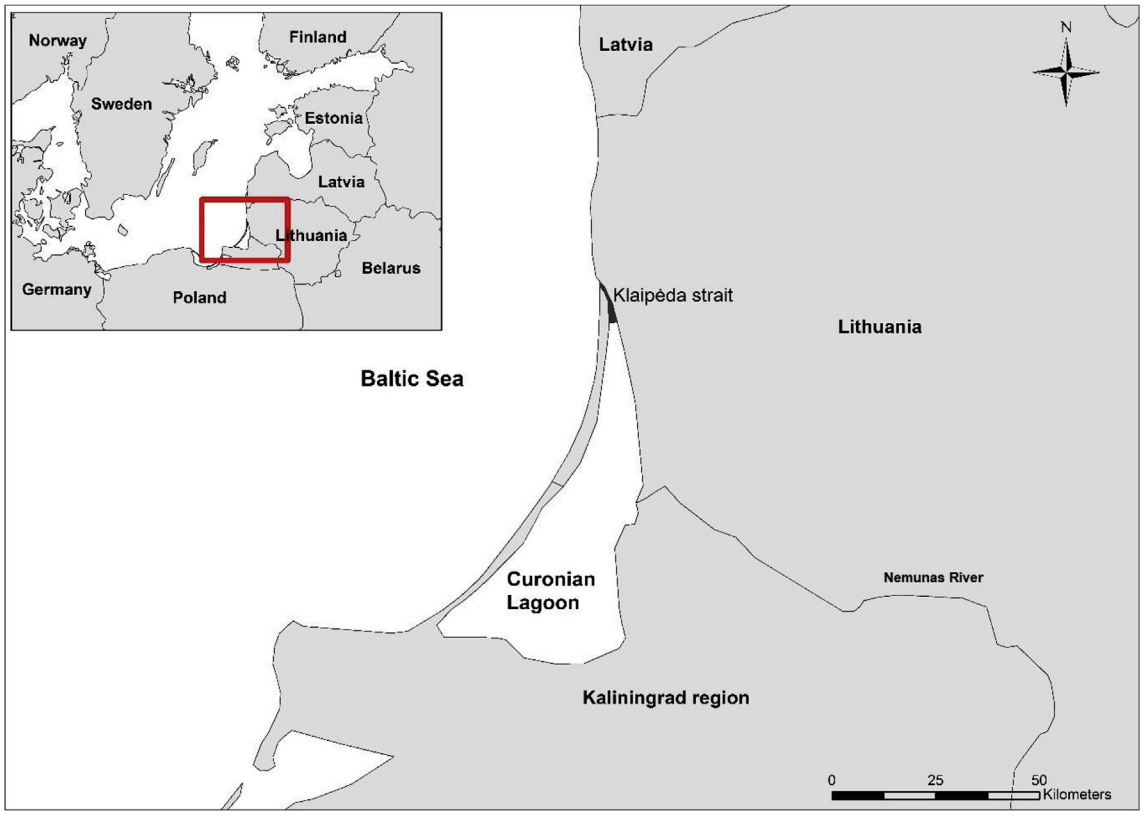

Fig. 1. The study area showing the Curonian Lagoon and its connection with the south-eastern Baltic Sea via the Klaipeda Strait at Latitude: 55°43′ 2.39″ N, Longitude: 21° 06′ 27.00″ E. The boundary between the Kaliningrad region and Lithuania intersects the eastern side of the Lagoon at the entrance to the Nemunas River.

may be more important in altering distributions of fish species in a freshwater lagoon or estuary (Blaber and Blaber, 1980), as the water temperature is known to be among the most important physical factors regulating the distribution of fish populations (Neuman, 1977). Effects of the interaction between salinity and temperature on fish growth rate, survival and associated physiological parameters are complex and are in general poorly known (Imsland et al., 2001). Some previous studies (Likongwe et al., 1996; Imsland et al., 2007; Magnussen et al., 2008; Imanpoor et al., 2012) demonstrated that growth and food conversion rates of juvenile and adult fish are affected by different temperature and salinity combinations, however values of optimal combinations are species and life stage dependent.

Since the 1960s, inflows of brackish water from the Baltic Sea to the freshwater Curonian Lagoon have increased (Jakimavičius & Kriaučiūnienė, 2013). According to daily data from the Marine Research Department, during 1986–2005 salinity in the northern region of the Lagoon has increased up to 1.6 (salinity was measured using the Practical Salinity Scale), whilst in the central and southern regions the water remained fresh. Under a changing climate, even more significant changes in salinity and temperature are projected into the future. In the northern part of the Curonian Lagoon salinity is expected to reach up to 2.6 and temperature is likely to increase by 2–6 °C by the end of the century (Jakimavicius et al., 2018). The variation in salinity and temperature in the Lagoon is driven by several factors: increased water level in the Baltic Sea, reduced Nemunas River runoff, increased frequency of westerly winds and channel dredging activities at the seaport in the Klaipėda Strait (Jakimavičius & Kriaučiūnienė, 2013). Similar increases in salinity have also been observed in other coastal estuaries connected to the Baltic Sea, such as the Vistula Lagoon (Cieśliński, 2016).

The expansive Curonian Lagoon potentially serves as an example of how a rapidly changing environment can affect a diverse freshwater estuarian system's ecological function and provision of ecosystem services which benefit society.

In order to mitigate or adapt to the negative effects caused by human activities that have increased carbon emissions into the atmosphere and warmed the seas, altering their physical dynamics and chemistry, e.g. acidification, thereby causing a range of adverse environmental changes (Chen et al., 2017; FAO, 2018), it is essential to understand how these environmental changes may impact on ecosystems that humans rely upon for food (FAO, 2018). Brackish water influxes from the sea into estuaries can potentially decrease freshwater fish production. This threatens the livelihoods of commercial fishers and reduces the availability of affordable locally caught fish. Reduced productivity will also impact adversely on the catching success of recreational anglers who fish for food and sport (FAO, 2018). Reduced participation in recreational angling will have a range of social and economic impacts in terms of sales of fishing tackle and equipment, as well as reducing the benefits that angling provides via relaxation for enjoyment, mental health, and welfare (McManus et al., 2011). The affinity with outdoor and natural environments and societal benefits that it fosters (Zelenski et al., 2015) would also be diminished.

In this study we tested the effects of increased water salinity and decreased temperature on the growth and behavioural responses of perch (*Perca fluviatilis* L.) under laboratory conditions to find out if there were any adverse effects. This combination of these two variables is consistent with projections of climate-driven changes in the Curonian Lagoon in Lithuania involving increased ingress of colder saline water from the Baltic Sea (Jakimavicius et al., 2018). Perch is the main predatory species in Curonian Lagoon (Repečka, 2003) and was chosen because global warming is widely predicted to strongly affect top predators and may even result in the total loss of some predatory species (O'Gorman et al., 2016). The results from this study will contribute to a better understanding about the potential consequences of future

changes for freshwater fish species in similar coastal ecosystems along the cool temperate margins of continents.

2. Material and methods

2.1. Study area

The non-tidal Curonian Lagoon (Fig. 1) is a large (1584 km^2), shallow (average depth 3.8 m) freshwater embayment connected to the South-Eastern Baltic Sea by a narrow (0.4–1.1 km) strait on which Klaipėda Port is located (Latitude: 55° 43′ 2.39″ N, Longitude: 21° 06′ 27.00″ E). Klaipėda Strait is an 11-km-long channel, artificially deepened to 15.5 m depth. The main freshwater inflow (90%) comes from the Nemunas River which enters the central part of the Lagoon about 50 km south of the strait (Gasiūnaitė et al., 2008). The Lagoon is classified as a eutrophic-to hypertrophic water body, with a fresh–brackish water gradient in its northern region where salinity irregularly fluctuates from 0 to 8 (Zettler and Daunys, 2007). The Curonian Lagoon is the most important water body for inland Lithuanian fisheries because it produces close to 100% of the national inland catches. The fish community of the Curonian Lagoon is dominated by roach (*Rutilus rutilus* (L.)), freshwater bream (*Abramis brama* (L.)), white bream (*Blicca bjoerkna* (L.)), perch (*Perca fluviatilis* L.), pike-perch (*Sander lucioperca* (L.)) and ruffe (*Gymnocephalus cernua* (L.)) (Repečka, 2003). The main top predators in the Lagoon ecosystem are large-size predatory perch and pike-perch, and piscivorous birds, such as great cormorant (*Phalacrocorax carbo* (L.)) and grey heron (*Ardea cinerea* L.) (Repečka, 2003; Žydelis and Kontautas, 2008).

2.2. Growth experiment under different salinity treatments

Perch young-of-the-year (YOY) captured using a beach seine in the northern region of the Curonian Lagoon (Latitude: 55° 38′ 17.19″ N, Longitude: 21° 9′ 6.68″ E) were used for the experiments. Perch were caught at the end of May when the water temperature was 17.9 °C and salinity was 0.3. After capture, perch YOY were transported to the experimental facility and acclimated to the laboratory conditions in three 300 L water tanks for 5 days. During the acclimation period perch were exposed to simulated day-night cycles of artificial light (Hagen Sun Glo T8 4200 K lamps; 12 h:12 h light/dark cycle). Water temperature in the acclimation tanks ranged between 17.0 and 19.0 °C and water was aerated with a steady air flow of 75 L min^{-1}. Concentrations of ammonium and nitrite were < 0.05 mg L^{-1} and the concentration of nitrate was < 15 mg L^{-1} for the duration of acclimation. No disease symptoms or mortality were observed during the acclimation period. The fish were then randomly divided into 15 experimental groups (10 fish in each group) and adapted to the experimental system for an additional five days.

The influence of water salinity on the growth of perch was studied using three separate recirculation systems, each with a different salinity: A) salinity 6, B) salinity 3 and C) freshwater (salinity 0). Curonian Lagoon is a freshwater system, but in a worst-case scenario average annual salinity is projected to increase up to 2.6 and in some months even up to 5 (Jakimavicius et al., 2018). Moreover, due to more frequent inflows of brackish water from the Baltic Sea, salinity in the northern region of the Lagoon may sometimes reach even more than 6 (Galkus, 2007; Zettler and Daunys, 2007). Thus, we consider natural and projected, long-term and short-term salinity effects. Previous work (Ložys, 2004) investigated the effects of temperature and salinity on the growth of percids: perch and pikeperch inhabiting the cooler, brackish waters of the Baltic Sea were found to have higher growth rates than those inhabiting the Curonian Lagoon. However, Bukantis et al. (2008) contradicted the previous (Ložys, 2004) findings about salinity, but not temperature. The primary hypothesis about growth in the current study was that increasing salinity in freshwater lagoons should not negatively affect fish distribution (which is the opposite to the hypothesis advanced by Bukantis et al., 2008), thus only the hypothesis about the effect of salinity on growth was tested.

Each experimental system consisted of five experimental square glass tanks (length = 0.5 m, width = 0.45 m, height = 0.4 m), each containing 80 L of water. To limit the distraction of the experimental fish, experimental aquariums were covered with black film (except the windscreen) and plates of transparent plastic on the top to limit water evaporation. To increase the water volume of the experimental system, an additional 200 L water tank was connected to the system. Five tanks were connected to the same biological and mechanical filter (Eheim 2180, Germany). Water was aerated in the 200 L water tank by aerators with steady air flow of 75 L min^{-1}. Water temperature was maintained by 500-W heaters and was the same in all experimental systems at the same time. During the growth experiment the water temperature ranged from 17.1 to 19 °C, which is similar to temperatures in the Curonian Lagoon from the end of May to June. The experimental systems were exposed to simulated day-night cycles of artificial light (Hagen Sun Glo T8 4200K lamps; 12 h:12 h light/dark cycle). Water flow rate from each experimental tank to the filter and back to tank was 3 L min^{-1} and was monitored twice per day. Water salinity was achieved by dissolving crude sea salt in freshwater. Salinity and temperature were monitored daily.

Prior to the experiment, the system was treated with an ammonia solution (10 ml day^{-1}) to achieve effective functioning of bio-filter and eliminate ammonium and nitrite compounds. The experiment started only after the ammonium and nitrite tests (Aquamerck Nitrite Test 14658, Aquaquant Ammonium Test 14400; Aquamerck Nitrate Test 11170; Merck, Germany) showed full absence of these compounds. Tests for ammonium and nitrite concentrations were performed daily, for nitrate at 3-day intervals. Samples for water quality tests were taken from outlet pipes of each tank. Concentrations of ammonium and nitrite were < 0.05 mg L^{-1} and the concentration of nitrate was < 35 mg L^{-1} for the duration of all experiments.

During all experiments, perch were fed daily *ad libitum* with live *Chironomus* spp. larvae. Perch in all replicates were fed at the same time and all uneaten larvae were removed two hours after feeding. Accumulated faeces were removed every day one hour before feeding the fish.

Prior to commencing the experiments, the perch were anesthetized (2-phenoxy ethanol; 0.8 ml L^{-1}) and individually marked by clipping a small part of one of the fins. Fish weight (± 0.01 g) for each replicate was measured prior to the beginning of the experiment and subsequently at 10-day intervals for the duration of the 60-day experimental period. Average initial weight and length of the experimental fish reared under freshwater, salinity 3 and salinity 6 treatments was 6.1 ± 1.25 g, 7.8 ± 0,8 cm (N = 50); 5.9 ± 1.22 g, 7.6 ± 1.0 cm (N = 50) and 6.0 ± 1.33 g, 7.7 ± 1.0 cm (N = 50), respectively. There were no significant differences in the initial fish weights and lengths between different treatments (salinities 0, 3 and 6; Kruskal-Wallis test, $P > 0.05$). To assess differences in growth under different treatments, the relative growth rate (RGR, %) was calculated using the following equation:

$$RGR = \frac{Q_2 - Q_1}{Q_1} \times 100$$

Where, RGR is relative growth rate (%), Q_1 is the initial weight, Q_2 is the final weight.

Fish health was monitored in each tank daily; no external symptoms of any diseases were noted during the experiment.

2.3. Behavioural experiment

Prior to commencing the experiments, perch for this experiment were captured using a beach seine in the Northern part of the Curonian Lagoon at the same place and time as those perch which were used for growth experiments and were acclimated to laboratory conditions as

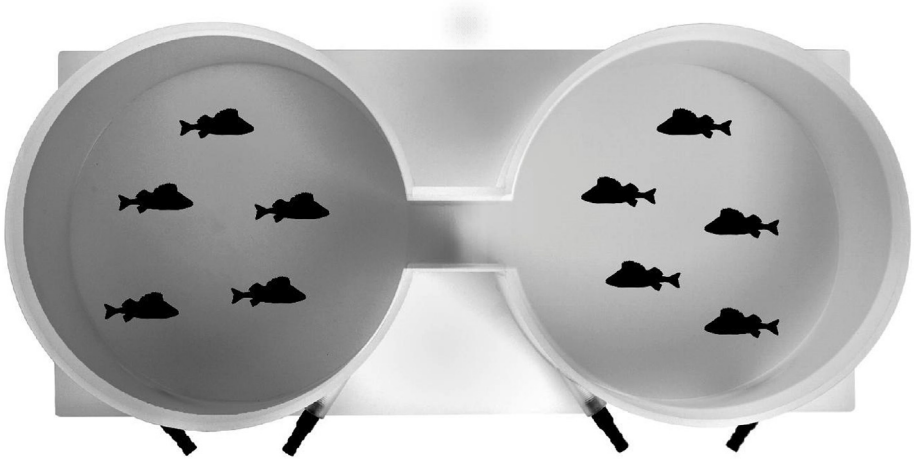

Fig. 2. Shuttle tank system (two 30 cm wide and 40 cm high chambers connected via an 8 cm long and 7 cm wide passage) used for the perch (*Perca fluviatilis* L.) behavioural experiments.

described above. Two types of behavioural experiments were performed to assess perch response to (1) salinity gradient (freshwater vs salinity 6) and (2) different temperature regimes (18 °C vs 12 °C) in shuttle tank system (Fig. 2), which is a modification of the device described by Schurmann et al. (1991) and Serrano et al. (2010). The 8-shaped shuttle box system maintains different constant water salinity or temperature in each of the chambers. The system consists of two 30 cm wide and 40 cm high chambers connected via an 8 cm long and 7 cm wide passage, through which the perch were able to move freely between compartments. The height of the water column in the chambers was 35 cm. Two additional water tanks (55 L each) with two dosage pumps for each of the two treatments were connected to the system. The experimental system was exposed to artificial light (Hagen Sun Glo T8 4200K lamps) in order to create a uniformly lit tank background.

Each trial used one group of ten fish and consisted of three periods: acclimation, control and test. In total, 15 trials were performed under each experimental treatment. Fish in the laboratory were pre-adapted to 15 °C freshwater. Each group was placed in a system and acclimated for 1 h in 15 °C freshwater. During this period, fish were able to swim freely to explore both chambers. During the next 10 min control period (with conditions being the same in both cylinders), fish position in one of the cylinders was recorded in 10 s intervals via a video camera (Canon Eos 5D Mark II) mounted over the shuttle box system. Immediately after the control period, different water salinity (freshwater vs 6) or temperature (18 °C vs 12 °C) treatments were introduced to the experimental chambers. Next, a second 30-min acclimation period was incorporated to allow fish to adapt to the treatments. This adaptation period was followed by the second test period, during which the position of fish was recorded for 10 min. No fish were tested more than once. The sides of the system containing warm/cold and fresh/brackish water in each trial were reversed. The nature and intensity of behavioural response were estimated by the Response Index (RI) (Svecevičius, 2007) through the formula:

$$RI = 50 \times (2 - \frac{N_T}{N_C})$$

Where, N_C is the average number of fish in one chamber (estimated every 10 s) during the control period i.e. when salinity and temperature is the same in both chambers; N_T is the average number of fish in the same chamber during the test period i.e. when the salinity or temperature gradient in each of the two chambers is held constant but at different levels.

The value of index 100 denoted maximal avoidance, while 0 signified maximal preference and 50 stood for indifference.

Behavioural choice experiments were conducted sequentially to compare responses to temperature (18 °C vs. 12 °C) and salinity (6 vs. 0), to determine preferences for warm or cold temperatures and for brackish or freshwater. The comparisons comprised cold freshwater vs. warm freshwater, followed by warm freshwater vs. warm brackish water, and finally warm freshwater vs. cold brackish water. Testing cold freshwater vs. cold brackish water was unnecessary given the clear preference of perch for warm brackish water in the first three tests. The cold brackish water combination mimics the situation when colder sea water flows into the Curonian Lagoon.

2.4. Data analysis

Differences in RGR between and within each salinity treatment were tested using the Kruskal-Wallis test ($P < 0.05$). The significance of test fish behavioural responses to changes in salinity and temperature was determined by comparing their mean RI value to the theoretically neutral response (50) using the Wilcoxon test ($P < 0.05$). This test was applied in separate for each treatment. The analysis was conducted using the statistical software package STATISTICA® 8.

3. Results

3.1. Growth experiment

At the end of the 60-day growth experiment, the mean RGR (%, mean ± SD) of perch was 13.2 ± 12.0 under freshwater treatment, while RGR under 3 and 6 water salinity treatments was 15.3 ± 11.8, and 13.9 ± 8.5, respectively (Fig. 3). There were no significant differences in perch RGR between different treatments of the same trial (Kruskal-Wallis test, $P > 0.05$). The lowest mean RGR was observed in the perch group reared in freshwater, however the difference was non-significant ($P > 0.05$).

3.2. Behavioural experiments

Results of the behavioural experiments demonstrated that perch had no preference for staying in any side of the experimental system when conditions were the same (warm freshwater vs. warm freshwater) in both sides (Table 1). However, perch preferred warm water (18 °C) over cold water (12 °C) and brackish water (salinity 6) over freshwater ($P < 0.05$). The strongest behavioural response (highest RI; Wilcoxon test, $P < 0.05$) was observed for warm brackish water vs. cold freshwater conditions. When the only difference in experimental conditions was temperature, perch significantly preferred warm water (Wilcoxon test, $P < 0.05$). If the difference between the chambers was water

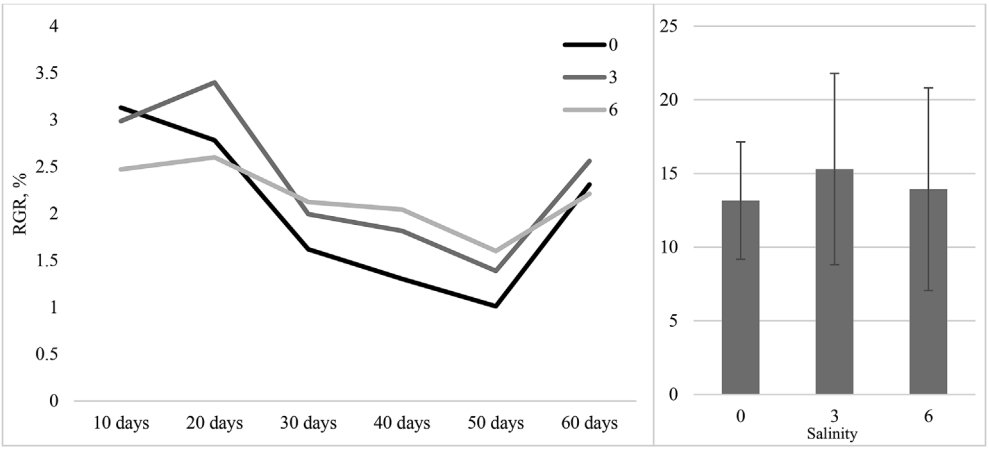

Fig. 3. Mean relative growth rate (RGR) in 10-day intervals (left) and during all the 60-day experimental period (right; RGR ± SD)) of perch (*Perca fluviatilis* L.) from the Curonian Lagoon (south-eastern Baltic Sea).

salinity, fish significantly preferred to stay in brackish water compared to freshwater (Wilcoxon test, $P < 0.05$). However, when experimental conditions were cold brackish water vs warm freshwater, perch stayed in warm freshwater (Wilcoxon test, $P < 0.05$).

4. Discussion

Climate change induces alterations in water temperature and salinity, which are in turn one of the main abiotic factors explaining fish distribution. In the Curonian Lagoon, changes in temperature and salinity are most apparent during water inflows from the Baltic Sea into the Lagoon. Though rise in water salinity has been suggested to be responsible for the decline of freshwater fish in the northern region of the Lagoon (Bukantis et al., 2008), our findings do not support this hypothesis. On the contrary, behavioural experiments demonstrated that perch prefer brackish water when given a choice between brackish and freshwater. Moreover, we found that brackish water has no effect on perch YOY growth.

Perch is a typical freshwater species that tolerates salinity up to 7–10 (Lutz, 1972). Overton et al. (2008) reported optimal growth of perch at salinities of 0–4, while 10 had a negative effect on perch growth performance. Nevertheless, increased growth rates among many freshwater fish species living in brackish water have often been observed (for a review, see Boeuf and Payan, 2001). We also recognised a slight acceleration of perch growth in brackish water compared to freshwater, although it was not statistically significant. Some previous studies (Lankford and Targett, 1994; Cardona, 2000; Boeuf and Payan, 2001; Hurst and Conover, 2002) support the hypothesis that the energetic cost of osmoregulation is lower in an isosmotic environment, where the gradients between blood and water are minimal, and that these energy savings are substantial enough to improve growth.

However, other life stages apart from YOY may be more susceptible to varying salinity (Victoria et al., 1992; Winger and Lasier, 1994). Bein and Ribi (1994) reported that perch hatching success and larvae survival are higher in brackish water (salinity 0.2–1.3) compared to freshwater and suggested that low concentration of salt in the water facilitates osmoregulation in larval fish. Klinkhardt and Winkler (1989) found the upper limit for hatching to be at salinity 7. Moreover, Christensen et al. (2016a) recently reported successful hatching of perch eggs *in vivo* for a Danish, western Baltic, brackish water population at salinities up to 12 and suggested that an upper limit (salinity of 7) reported by Klinkhardt and Winkler (1989) might have been downwardly biased by the high incubation temperature (18–20 °C) during the experiment, as it is known that temperature > 14 °C increase egg mortality (Guma'a, 1978). Interestingly, Tibblin et al. (2012) reported reduced survival and growth of perch from both freshwater and brackish origins during younger life stages (yolk-sac larvae and fry < 90 days old) in brackish water. They suggested that the perch had not developed any tolerance to brackish water (salinity 7) during their younger life stages, although hatching success was not affected by brackish water. Tibblin et al. (2012) suggested that fish which cope and reproduce in salinities up to 10 still use reproduction sites with salinities below 2.5 (Muncy, 1962; Victoria et al., 1992).

Nevertheless, it is clear that freshwater fish species can tolerate brackish water. It is known, that perch and pikeperch (*Sander lucioperca* (L.)) migrate to the coastal waters of the Baltic Sea during the warm water season and return to the Curonian Lagoon for wintering (Ložys, 2004). Such behaviour of perch and pikeperch is also observed in other brackish regions of the Baltic Sea (Lucas and Baras, 2001), and for yellow perch *Perca flavescens* (Mitchill) in North America (Craig, 1987), which suggests that there are no negative effects of brackish water on perch in their natural environment. Behavioural laboratory experiments demonstrated that perch responded negatively to cold water compared to warm, and freshwater compared to brackish. We believe that these results can be applied in understanding perch behaviour in the field. Increase in the frequency of strong onshore north-westerly and westerly winds (Dailidienė et al., 2006) is likely to cause seawater to back-up against the coast at Klaipeda forcing larger volumes of colder brackish water from the Baltic Sea to flow through the Klaipeda Strait into the Lagoon. During such inflows water temperature in the northern region of the Lagoon may temporarily decrease by 4–5 °C while salinity increases from 0 up to even 7. Due to the lower seawater temperature,

Table 1
Response indexes (RI) of perch (*Perca fluviatilis* L.) from the Curonian Lagoon (south-eastern Baltic Sea).

Type of the experiment	Response index (mean ± SD, N = 15)	Wilcoxon test results
Warm freshwater (18 °C, salinity 0) – Warm freshwater (18 °C, salinity 0)	48.8 ± 3.6–51.2 ± 3.6	$W_{14} = 82.5$, $P = 0.2$
Cold freshwater (12 °C, salinity 0) – Warm freshwater (18 °C, salinity 0)	89.4 ± 2.7–10.6 ± 2.7	$W_{14} = 120$, $P = 0.0006$
Warm freshwater (18 °C salinity 0) – Warm brackish water (18 °C, salinity 6)	88.6 ± 4.5–11.4 ± 4.5	$W_{14} = 120$, $P = 0.0006$
Cold brackish water (12 °C, salinity 6) – Warm freshwater (18 °C, salinity 0)	89.8 ± 2.7–10.2 ± 2.7	$W_{14} = 120$, $P = 0.0006$
Cold freshwater (12 °C, salinity 0) – Warm brackish water (18 °C, salinity 6)	94.3 ± 2.8–5.7 ± 2.8	$W_{14} = 120$, $P = 0.0006$

perch (and likely other freshwater fish species) may temporarily leave cold water zones and move further into the Lagoon; however, this effect should be short-term and after the temperature of the seawater increases, the fish should return to the brackish areas in the Lagoon. Thus, in a long-term perspective the northern region of the Curonian Lagoon should become even more attractive for perch since the highest RI results were observed under warm (18 °C) and brackish (salinity 6) water treatments.

Jakimavičius et al. (2018) project a significant increase of water temperature of the Curonian Lagoon in the 21st century: the temperature is expected to increase by 1.7 °C in the near future (until 2035), or even by 6.3 °C in the far-future (until 2100) under a worst-case scenario. Our results show that temperature may play a significant role in perch behaviour as demonstrated by their strong preference for 18 °C water when compared with colder (12 °C) water. In addition, growth rates in perch slow or cease at temperatures ≤10 °C (Karás, 1990), thereby implying that increases in water temperature above 10 °C during the cold-water periods of the year should have a positive effect on the growth of perch in the Lagoon. On the other hand, if during the warm-water season the water temperature attains lethal or sublethal levels then it might have a strong negative effect. In the Curonian Lagoon, the most profound climate change-driven increase in water temperature will take place during summer (Jakimavicius et al., 2018) – the maximum mean temperatures are expected slightly exceed 26 °C in July and August, thus water temperature will be above the perch physiological optimum which is known to be c. 25.4 °C (Hokanson, 1977), however, still well below lethal temperatures for the species, which are reported to be in the range of 30.0 and 36.7 °C (Hokanson, 1977; Neuman, 1979).

Furthermore, temperature is a trigger for spawning and in the Curonian Lagoon perch spawning is usually observed in freshwater areas when the temperature ranges between 8 and 13 °C at the end of April – beginning of May. Because of increasing water temperature some shift in the spawning period towards earlier dates is expected which may improve perch survival and growth during the first year of life (Irwin et al., 2009). Salinity is expected to rise to values around 2.6 during the perch spawning period (Jakimavicius et al., 2018), which should not affect perch spawning in the Lagoon given that Christensen et al. (2016a) reported successful hatching of perch eggs at salinities up to 12.

5. Conclusion

Our study demonstrates that perch are likely to prefer remaining in brackish water even for longer periods and that this will not reduce their growth rates. The experiments indicated positive behavioural responses towards brackish salinities which is consistent with observed perch migration to the coastal waters of the Baltic Sea during the warm-water season. We believe that temperature, not salinity, primarily drives short-term changes in fish distribution within the Curonian Lagoon during inflows of colder brackish water from the Baltic Sea. Forecasted changes in water temperature (Jakimavicius et al., 2018) are not expected to have a negative impact on perch in the Lagoon because temperatures are unlikely to exceed the physiological optimum for perch under most climate scenarios in the near- and far-future. Moreover, some increase in temperature should stimulate perch growth and cause a favourable shift in spawning period. Projected increases in water salinity (Jakimavicius et al., 2018) are also unlikely to negatively affect perch. It should be noted that the results from our study reflect the direct impact of brackish water on perch growth and behaviour at the juvenile stage, and that other early life stages were not considered. There may be also other effects on the distribution of fish populations in the Curonian Lagoon related to changes in the inflowing water from the Baltic Sea. These may include changes in water turbidity and dispersion of inflowing water from increase in windiness and sea temperature, and the way these factors interact with salinity (Claireaux and Lagardère, 1999; Imsland et al., 2001). Acquiring a more comprehensive understanding of the effects of interactions between increasing salinity and temperature on the fauna of freshwater lagoon environments, such as the Curonian Lagoon, requires further studies. These studies should be conducted from a trophic perspective to evaluate impacts of water salinity on various freshwater pelagic and benthic invertebrates, which are important food for fish in the Lagoon.

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